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ABSTRACT

This paper describes a simple global climate model useful in a freshman or sophomore level course in climatology. There are three parts to the paper. The first part describes the model, which is a global model of surface air temperature averaged over latitude and longitude. Samples of the types of calculations performed in the model are provided. The second part of the paper discusses the computer code. The model is coded in Fortran-77 and requires about 45K bytes of storage in executable form. It can, therefore, be run on almost any machine. Part three discusses how the model can be used to illustrate several features of the global energy balance. Students might be asked to invent a scenario and investigate the climatic consequences. Or the model can illustrate concepts such as equilibrium, relaxation time and thermal inertia, positive and negative feedbacks, and stability. Among the virtues of this model are its small size, its robustness to user abuse, and its ability to illustrate at least qualitatively a large number of features of global climate. (RM)

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A GLOBAL CLIMATE MODEL FOR INSTRUCTION

by

James E. Burt

University of Wisconsin-Madison

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A GLOBAL CLIMATE MODEL FOR INSTRUCTION

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INTRODUCTION

It is ironic that some of the very attributes of climate models which confound their use in research enhance their potential as educational devices. Simplification, the neglect of many processes and feedbacks, and the use of variables with intuitive rather than physical interpretation all contribute to a mathematical structure whose behavior and internal consistency can be much more easily understood. In many respects climate models are perhaps better suited to instruction than research. In this session we attempt to explore the educational utility of a group of models representing both a range of complexity and a variety of physical systems. The participants have kindly agreed to make their models available to anyone requesting a copy, and those attending the session are encouraged to use these models in their own courses as appropriate.

This paper describes a simple global climate model useful in a freshman or sophomore level course in climatology. After a brief discussion of the relevant theoretical and semi-empirical equations, the presentation focuses on the design of the computer code, and how the model can be used in a climatology course. I attempt to outline some of the concepts this model is able to illustrate, and I suggest some typical projects that might be assigned.

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DESCRIPTION OF THE MODEL

The model is a global model of surface air temperature averaged over latitude and longitude. This fictitious temperature is computed on the basis of energy balance and follows very closely the description of planetary energy balance given by Paltridge and Platt (1976). Although only a single equation is carried, the planet is subdivided into a cloudy and clear portion, n and $(1-n)$, respectively. Heat fluxes are computed separately for the two portions, with the time rate of change of temperature given by

$$dT/dt = (1/C) * [n * F_c + (1 - n) * F_o]$$

where C is planetary heat capacity (a function of mixed layer depth) and F_c and F_o are net radiation absorbed by the cloudy and clear portions of the planet. The energy fluxes are highly parameterized in terms of surface temperature, so that the model is a closed system and does not require knowledge any other variables (such as temperature at other levels). The parameterizations are expressed as functions of 13 constants, e. g., solar output, atmospheric CO_2 concentration. These constants, which constitute the model parameters, all default to standard values which cause the model to come to equilibrium at $15.4^\circ C$.

Space does not permit a complete presentation of the model and its parameters, but it is possible to illustrate the type of calculations performed. For example, solar flux absorbed by the clear portion of the planet is found from

$$S_0 = (S/4) * (1 - n) * (1 - r)$$

where S is the solar parameter and r is the shortwave reflectivity of the clear portion of the planet (surface plus atmosphere). The model includes both temperature-albedo and temperature-cloud feedbacks, so that n and r are functions of temperature. Letting T^* , n^* and r^* be the standard (or equilibrium) values of temperature cloud fraction and albedo, we have

$$n = n^* + n' * (T - T^*)$$

$$r = r^* + r' * (T - T^*)$$

where n' and r' are the cloud and albedo feedbacks. Analogous equations hold for the cloudy fraction of the planet. Longwave fluxes are calculated as a function of temperature using parameters related to infrared emissivity of surface, clouds, and atmosphere.

COMPUTER CODE

As is obvious from the discussion above, the model consists of a single differential equation which must be integrated forward in time. As written above, the rate of temperature change depends on the current temperature and the values assigned to the parameters. Under normal circumstances the parameters are fixed in time, thus the temperature typically relaxes to a new equilibrium temperature appropriate for the particular combination of

parameter values in effect for the run.

The code was designed so that the user can modify any of the 13 parameters at will. When a parameter is changed no attempt is made to determine if the change is realistic. This is intentional and reflects my belief that absurd values often provide useful information. A student might, for example, find it reassuring to observe that when the solar parameter is zero, the planetary temperature does approach 0 K. Not knowing what values will be input puts an additional burden upon the integrator, and the code had to be made sufficiently robust that simulations could proceed regardless of parameter values.

The program operates by prompting the user for changes in parameter values. After all changes have been made, it then asks for a starting temperature. The user then selects the length of integration and an external time step used to determine the points at which the solution will be observed. The program integrates forward using a variable internal time step which is maintained just small enough to ensure local errors are less than an error tolerance (typically 0.001 K). This provides both efficiency and much of the code's ability to withstand wild parameter values.

The model is coded in Fortran-77, and requires about 45K bytes of storage in executable form. It can therefore be run on almost any machine, but if a microcomputer is used interaction may be unacceptably slow unless floating point operations are performed rapidly.

USE OF THE MODEL

At its most basic level, the model illustrates several features of the global energy balance. The model has been tuned so that computed fluxes to space agree very closely with satellite observations. Also, those parameters which have direct interpretation (e. g., cloud amount, CO_2 concentration) are set at generally accepted values. This means that students can be given exercises that walk them through several simulations, and values obtained for default conditions will agree with those presented in lecture and/or the textbook. Such an exercise might ask about what is happening to energy fluxes as the planet approaches equilibrium, or it might ask a student to speculate about how fluxes will change if some parameter is changed. The idea here would be to get the student used to reasoning from physical principles, first asking them to explain what is seen, then asking for an extrapolation. Because the student can verify the speculation immediately, a very tight educational feedback loop is operating.

When used in a perturbation mode, the student can perform a number of "what if" experiments--included here would be the standard solar parameter changes, CO_2 doublings, and so forth. An interesting variant is to look for competing effects; that is, how large a change in one parameter is required to offset a given change in some other parameter? Typical assignments in this vein might involve asking students to invent a scenario (10% change in solar output, 5% change in cloudiness due to SST's, etc.) and investigate the climatic consequences. Thoughtful students will

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interpret the results both in terms of model equations and in terms of what would be expected in the real atmosphere. My experience has been that students often want to use the model in some way that calls for a modification of the code. For example, a student might want to inject CO_2 slowly into the atmosphere rather than instantaneously double the concentration. Because the climatology is completely isolated in one subroutine, it is easy for an instructor (or student) to make required changes. The integrator should have no trouble with time-dependent forcings, providing they are continuous and reasonably smooth (C^1 continuity is usually sufficient).

A final use of the model is to illustrate a number of very general concepts commonly used when describing the behavior of world climate, and other complex dynamic systems. These include equilibrium, relaxation time and thermal inertia, positive and negative feedbacks, and stability. For example, judicious adjustment of model parameters leads to multiple equilibrium climates, not all of which are stable. (It is very easy for a student to perform an empirical stability analysis by simply perturbing starting temperatures slightly after locating an equilibrium point.) I have found it effective to first present the concepts in lecture, and then give an assignment in which the student "discovers" examples of the concepts. After watching global temperature accelerate off an equilibrium point, students seem to acquire a much firmer grasp of these rather abstract notions. Naturally, with such a highly simplified model, no emphasis is placed on the particular parameter values leading to the observed behavior.

CONCLUSIONS

The very simple model described here has proven itself pedagogically useful in a variety of ways. Among its virtues are its small size, its robustness to user abuse, and its ability to illustrate at least qualitatively a large number of features of global climate. Its limitations arise mainly from the extreme parameterizations employed and its absence of spatial resolution. An instructor in an intermediate or advanced course might use this model early in the term as an introduction to climate models, but would be advised to give serious consideration to the models presented by later papers in this session.

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